CLAIMS

1. A method of determining the phase and/or amplitude information of an electromagnetic wave

- in which an electromagnetic wave is radiated onto the surface of a photonic mixing element having at least one pixel, wherein the pixel has at least two light-sensitive modulation photogates G_{am} and G_{bm} and associated accumulation gates G_a and G_b,

- in which there are applied to the modulation photogates G_{am} and G_{bm} modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ which are in the form of $U_{am}(t) = U_o+U_m(t)$ and $U_{bm}(t) = U_o-U_m(t)$,

- wherein applied to the accumulation gates G_a and G_b is a dc voltage whose magnitude is at least as great as the magnitude of the sum of U_o and the amplitude of the modulation voltage $U_m(t)$,

- in which the charge carriers produced in the space charge zone of the modulation photogates G_{am} and G_{bm} by the incident electromagnetic wave are exposed to the potential gradient of a drift field in dependence on the polarity of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ and drift to the corresponding accumulation gate G_a and G_b, and

- in which the charges q_a and q_b which have drifted to the respective accumulation gates G_a and G_b are taken off.

2. A method according to claim 1

- in which an intensity-modulated electromagnetic wave is irradiated by a transmitter,

- in which the electromagnetic wave reflected by an object is radiated onto the surface of the photonic mixing element,

- in which the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ are in fixed phase relationship with the phase of the electromagnetic wave irradiated by the transmitter, and

- in which the charge carriers produced are

additionally exposed to the potential gradient of a drift field in dependence on the phase of the push-pull modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$.

3. A method according to claim 2

- in which for two different phase shifts $\Delta_{\varphi 1}$ and $\Delta_{\varphi 2}$ of the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ relative to the phase of the electromagnetic wave irradiated by the transmitter the charges q_{a1} and q_{b1} as well as q_{a2} and q_{b2} are taken off and the charge differences $(q_{a1} - q_{b1})$ and $(q_{a2} - q_{b2})$ are formed, and
- in which in accordance with the equation

$$\varphi_{opt} = \frac{q_{a2} - q_{b2}}{q_{a1} - q_{b1}}$$

the pixel phase φ_{opt} of the incident electromagnetic wave is determined relative to the phase of the electromagnetic wave irradiated by the transmitter and thus the transit time of the electromagnetic wave received by the pixel is determined.

4. A method according to claim 3

- in which by means of four modulation photogates G_{am}, G_{bm}, G_{cm} and G_{dm} and four associated accumulation gates G_a, G_b, G_c and G_d, for two different phase shifts $\Delta_{\varphi 1}$ and $\Delta_{\varphi 2}$ of the modulation photogate voltages $U_{am}(t) = U_o + U_{m1}(t)$ and $U_{bm}(t) = U_o - U_{m1}(t)$ and $U_{cm}(t) = U_1 + U_{m2}(t)$ and $U_{dm}(t) = U_1 - U_{m2}(t)$ relative to the phase of the electromagnetic wave irradiated by the transmitter, at the same time the charges q_a, q_b, q_c and q_d are separated and taken off, and
- in accordance with the equation

$$\varphi_{opt} = \frac{q_c - q_d}{q_a - q_b}$$

the pixel phase φ_{opt} of the electromagnetic wave irradiated by the transmitter and therewith the transit time of the electromagnetic wave received by the pixel is determined.

5. A method according to one of the preceding claims

- in which the photonic mixing element has a plurality of pixels,
- in which at least one pixel is directly radiated with a part of the intensity-modulated electromagnetic wave from the transmitter and
- in which calibration of the phase shift between the irradiated electromagnetic wave and the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ is implemented from the phase shift measured with said pixel.

6. A method according to claim 1

- in which an electromagnetic wave with independently excited, unknown intensity modulation is radiated onto the surface of the photonic mixing element,
- in which the modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$ are produced by a tunable modulation generator,
- in which the charge carriers produced are additionally exposed to a potential gradient of a drift field in dependence on the phase of the push-pull modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$, and
- in which the photonic mixing element and the modulation generator form at least one phase-lock loop and the electromagnetic wave is measured in accordance with the lock-in method.

7. A method according to one of claims 1 to 6 in which a continuous or discontinuous HF-modulation, pseudo-noise modulation or chirp modulation is used as periodic modulation.

8. A method according to claim 7 in which the modulation is HF-modulation and preferably the charges q_a and q_b and possibly q_c and q_d for the phase shifts Δ_φ = $0^\circ/180^\circ$ and $90^\circ/270^\circ$ are taken off.

9. A method according to claim 1 in which a steady-state modulation is used with modulation photogate voltages $U_{am} = U_o + U_{m0}$ and $U_{bm} = U_0 - U_{m0}$ with a settable modulation dc voltage U_{m0} which is constant in respect of time and with which the difference image from the difference of the charges q_a and q_b is specifically weighted.

10. A method according to one of claims 1 to 9 in which the charges q_a and q_b beneath the accumulation gates G_a and G_b are integrated and read out with a multiplex structure, preferably with a CCD-structure.

11. A method according to one of claims 1 to 9 in which the accumulation gates G_a and G_b are in the form of pn-diodes, preferably blocked low-capacitance pn-diodes and preferably using CMOS-technology, and in which the charges q_a and q_b and possibly q_c and q_d are read out directly as voltage or as current.

12. A method according to claim 11 in which the pixel phase or the pixel transit time and the pixel brightness are ascertained directly by means of an active pixel sensor structure (APS) and preferably selectively and/or serially read out by way of an on-chip multiplex structure.

13. A method according to one of claims 1 to 12 in which the pixel brightness is respectively evaluated as the sum of the charges of the associated accumulation gates as a grey value image.

14. A method according to one of claims 1 to 13 characterised in that in the case of background lighting or an external, non-modulated additional lighting, the difference of the grey value images is used as a correction parameter on the one hand when the modulated lighting is

switched on and on the other hand when the modulated lighting is switched off.

15. A method according to one of claims 1 to 14 characterised in that a plurality of separate mixing elements are used in a linear, surface or spatial array.

16. A method according to claim 15 characterised in that at least one of the pixels is directly radiated with a part of the intensity-modulated electromagnetic wave serving as lighting and that the measurement at said at least one pixel is used for calibration of the other phases and brightness results, wherein preferably the reference pixel or pixels is or are acted upon by the transmitter with different levels of intensity or levels of intensity which can be differently set.

257/222

Subcombination

17. A photonic mixing element
- with at least one pixel (1),
- which has at least two light-sensitive modulation photogates (G_{am}, G_{bm}) and
- accumulation gates (G_a, G_b) which are associated with the modulation photogates (G_{am}, G_{bm}) and which are shaded relative to the incident electromagnetic wave.

18. A mixing element according to claim 17 characterised in that a middle gate (G_0) is arranged between the modulation photogates (G_{am}, G_{bm}).

19. A mixing element according to claims 17 or claim 18 characterised in that the pixel (1) has four, preferably symmetrically arranged, modulation photogates (G_{am}, G_{bm}, G_{cm}, G_{dm}) and accumulation gates (G_a, G_b, G_c, G_d).

20. A mixing element according to one of claims 17 to 19 characterised in that the accumulation gates (G_a, G_b and

possibly G_c, G_d) are in the form of pn-diodes, preferably blocked, low-capacitance pn-diodes and preferably of CMOS-technology, and the charges q_a, q_b and possibly q_c, q_d can be read out directly as voltage or current.

21. A mixing element according to one of claims 17 to 20 characterised in that for the purposes of increasing the maximum modulation speed the pixel is produced using GaAs-technology, preferably of "buried channel" type (for example a buried n-channel) and with an integrated drift field.

22. A mixing element according to one of claims 17 to 21 characterised in that the pixel (1) is in the form of an active pixel sensor structure with partially pixel-related signal processing and partially line- or possibly matrix-related signal processing.

23. A mixing element according to one of claims 17 to 22 characterised in that the shading is also extended onto the edge regions of the modulation photogates.

24. A mixing element arrangement having at least two photonic mixing elements according to one of apparatus claims 17 to 23 characterised in that the photonic mixing elements are arranged in a one-dimensional, two-dimensional or three-dimensional arrangement.

25. A mixing element arrangement according to claim 24 characterised in that modulation photogates ($G_{am,n}$, $G_{am,n+1}$) and ($G_{bm,n}$, $G_{bm,n+1}$) respectively associated with two adjacently arranged, different pixels (n, n+1) respectively have a common accumulation gate (G_s) and that the modulation photogates ($G_{am,n}$, $G_{am,n+1}$) and ($G_{bm,n}$, $G_{bm,n+1}$) respectively are acted upon by the same modulation photogate voltages $U_{am}(t)$ and $U_{bm}(t)$.

Combin 250

26. A mixing element arrangement according to claim 24 or claim 25 characterised in that there are provided devices for the direct irradiation of at least one pixel (1) as a reference pixel, by means of which a part of the intensity-modulated electromagnetic radiation emitted by the transmitter is directed onto the pixel or pixels in question.

27. A mixing element arrangement according to claim 26 characterised in that the devices for direct irradiation are equipped for a variation in respect of space and/or time of the intensity of the direct irradiation.

28. A one-dimensional or multi-dimensional mixing element arrangement according to one of claims 24 to 27 characterised in that the pixels (1) are embodied using MOS-technology on a silicon substrate (2) and can be read out with a multiplex structure, preferably with a CCD-structure.

29. A mixing element arrangement according to one of claims 24 to 28 characterised in that there is provided a microlens optical system which produces substantially for each mixing element used for image recording its own microlens by which the incident radiation is focussed onto a central region of the mixing element which can thus be reduced in size.

Combin.

30. Apparatus for determining the phase information of an electromagnetic wave

- having at least one photonic mixing element according to one of apparatus claims 17 to 23,
- having a modulation generator (10, 13), and
- having a transmitter (4) whose irradiated electromagnetic wave is intensity-modulated by the modulation generator (10, 13) in predetermined manner,

- wherein the electromagnetic wave which is reflected by an object (6) is radiated onto the surface of the photonic mixing element, and

- wherein the modulation generator (10, 13) supplies the photonic mixing element with modulation voltages $U_m(t)$ which are in a predetermined phase relationship with respect to the phase of the irradiated electromagnetic wave from the transmitter.

31. Apparatus according to the preceding apparatus claim characterised in that there are provided an optical system (7) and a mixing element arrangement possibly according to one of claims 24 to 29, wherein the optical system (7) forms the image of the reflected electromagnetic wave on the surface of the mixing element or the mixing element arrangement.

32. Apparatus according to claim 30 or 31 characterised in that there are provided a mixing element arrangement with associated optical receiving system, electronic evaluation and signal processing system for the difference signals, sum signals and associated reference signals, with a digital memory for the grey value image and the transit time or distance image, a transmitter for lighting a three-dimensional scene with modulated electromagnetic waves, and with an adjustable optical transmitting system corresponding to the optical receiving system, forming a digital 3D-photographic camera in the form of a compact unit.

33. Apparatus according to claim 30 or 31 characterized in that to form a digital, three-dimensionally recording video camera, there are provided mixing element arrangement with associated optical receiving system, electronic evaluation and signal processing system for the difference signals, sum signals

and associated reference signals, with a digital memory for the grey value image and the transit time or distance image, a transmitter for lighting a three-dimensional scene with modulated electromagnetic waves, and with an adjustable optical transmitting system corresponding to the optical receiving system, wherein there are further provided memory means for the storage of digital image sequences.

34. Apparatus according to claim 32 or 33 characterised in that the transmitter is provided with devices for emitting light waves in various spectral regions for producing colour images or colour image components.